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Acoustical and optical measurement for monitoring the cavitation related activities in a cylindrically focused acoustic field.

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1. Introduction

Cavitation has been widely used in various industrial fields. For example, cavitation has been applied to produce materials such as carbon nano-tubes[1,2] or to disperse nanometer sized diamond particles[3]. Therefore, it is necessary to monitor cavitation to ensure its activities. However, there is currently no standard method for measuring the degree of cavitation. Passive cavitation detector or PVDF needle hydrophone would be the first choice to measure the acoustic signal emitted from cavitation bubbles. However, they are not suitable for cavitation activities produced in a cylindrically focused ultrasonic field which recently was reported to be industrial utility [4].

The present study reports the measurement of cavitation related a quantity related to cavitation collapse in a cylindrically focused field using a cylindrical needle type cavitation sensor, combined with photomultiplier (PMT). The fabricated cylindrical cavitation sensor was designed to be geometrically compatible with a cylindrically focused acoustic field.

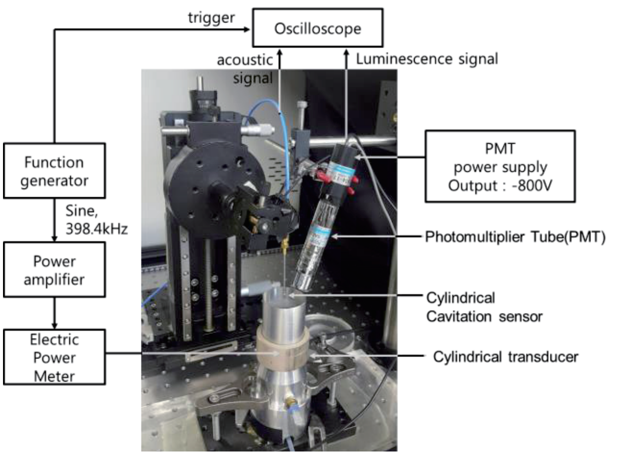

Fig 1. A schematic block diagram of the experimental setup.

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2. Materials and methods

A single element, cylindrically focused ultrasonic transducer was used to produce the acoustic field and the resulting cavitation bubbles. The transducer has the radius of 20 mm and length of 25 mm, and it is resonated at the frequency of 398.4 kHz. RF signal was supplied by a function generator (33250A, Agilent, USA) was amplified in a power amplifier (HAS 4012, NF, USA) to generate ultrasonic waves. Electric power supplied to the ultrasonic transducer was measured by an electric power meter (PM2002, Amplifier Research, USA) (Fig 1).

A cavitation sensor was constructed for the present study. It has a cylindrical sensing element at the tip and is geometrically compatible with a cylindrically focused ultrasonic transducer. A PVDF-TrFE membrane band (with a width of 2mm) was used as the sensing element. ~~and~~ It was wrapped around the copper rod (with the diameter of 2mm, height of 3mm) used for cylindrical base ~~and~~ as well as signal transmission path.

PMT(R2027, Hamamatsu Photonics, Japan) was used to sense the emission of light as the result of chemical reaction inside cavitation bubbles in luminol(98%, Alfa Aesar, USA) solution. The cavitation sensor was precisely located at the center of the ultrasonic transducer and the PMT was also aligned towards the center of the transducer. The signals from the cavitation sensor and PMT were simultaneously recorded on digital oscilloscope (NI-5122, 100MS/s, NI, USA).

High-frequency components, more than 10 times higher than driving frequency (398.4 kHz) of the signal from the cavitation sensor signal was understood to result from cavitation related signal caused by the inertial collapse of bubbles[5,6]. Accordingly, the broadband noise integral (BNI) was calculated by integrating the high-frequency components above 4 MHz. BNI is defined by the following equation[7,8] :

$$V(f) = \int_{-\infty}^{\infty} v(t) e^{j2\pi ft} dt \qquad (1)$$

$$BNI = \int_{f_{low}}^{f_{high}} \left| V(f) \right| df \qquad (2)$$

where *v(t)* is the output signal from the cavitation sensor and *V(f)* represents the frequency spectrum. The frequency range for the integral f_{low} and f_{high} were respectively set to 4 and 50 MHz.

It is likely that, before the output from PMT rises with significance, the cavitation sensor output does not contain the broadband acoustic emission resulting from inertial cavitation collapse. The energy of the acoustic emission may be effectively normalized to the background noises, which is termed 'broadband noise integral ratio (BNIR)' calculated as a ratio of BNI to that without inertial cavitation collapse between cavitation collapse free and contamination range.

$$BNIR(dB) = 20\log_{10}\left(\frac{\text{cavitation contamination}}{\text{cavitation free}}\right) \tag{3}$$

The window size of signal was 50 μs and the moving time interval was 5 μs.

3. Results and Discussion

Fig. 2 shows the typical output signals measured at the contrasting two power settings of 1.7 W and 21.6W, together with the BNIR (black line) as well as PMT output (red line).

The time delay of ultrasonic wave from transducer surface to the cavitation sensor is approximately 13 us and the waveform oscillates until 2.5 ms (Fig 2(a) and 2(b)). As seen in Fig. 2(c) and 2(d) The PMT did not response in the low power setting, which means that there are no inertial cavitation activities. The PMT signal starts to rise from approximately 200 μs and reaches maximum value around 2.5 ms as shown in Fig 2(d). The PMT output begins to rapidly decrease when the ultrasonic transducer stops operating. The BNIR shows a similar tendency to the PMT signal.

4. Conclusions.

The cylindrical needle shape cavitation sensor was shown to effectively detect the acoustic emission resulting from cavitation collapse in a cylindrical focused acoustic field. The BNIR was found to have a similar structure to PMT output, suggesting that PMT is useful to assess if the cavitation signal contains the acoustic emission from inertial bubble collapse. Further study is underway to obtain the parameter BNIR without PMT.

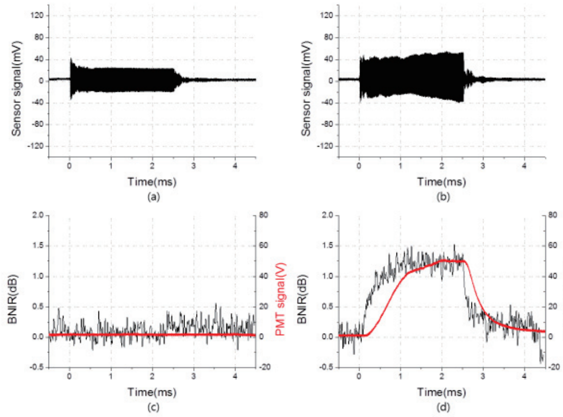

Fig 2. Cavitation sensor outputs (top panels) measured at the power setting of (a) 1.7W and (b) 21.6W, and PMT signal (red line) and the time history of the BNIR (bottom panels) at each setting.

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